Evaluation of the AoR Delineation Modeling Approach in Carbon TerraVault's Monterey Formation A1-A2 Class VI Permit Application

This area of review (AoR) delineation modeling evaluation report for the proposed Carbon TerraVault 1 LLC (CTV) Class VI geologic sequestration project summarizes EPA's review of the modeling performed by CTV as described in the Area of Review and Corrective Action Plan (AoR CA), which is Attachment B to CTV's August 2021 permit application and associated files submitted to the AoR and Corrective Action Module of the GSDT. This review also addresses modeling-relevant site characterization information in the permit application narrative and in the PISC and Site Closure Plan (Attachment E). Because the AoR modeling accounts for both of CTV's proposed injection wells (357-7R and 355-7R), this evaluation applies to both wells. Clarifying questions for CTV and requests for supplemental information are provided in blue within the text below.

This report describes and evaluates how site-specific data (e.g., geologic data and planned operational conditions) described in the UIC permit application are incorporated into CTV's geomodel and their computational modeling approach. Note that EPA did not perform independent, duplicative modeling of CTV's AoR. It is assumed, however, that planned pre-operational testing will confirm the site characterization information. Please note that modifications to the model parameters may be needed if this testing yields results that are significantly different than the model inputs.

Evaluation of the Geomodel

Representation of Site Geologic Features

To delineate the Class VI AoR, the geological layering, formation thicknesses, and petrophysical properties of the project site (as described in the permit application narrative and evaluated in the geologic site characterization report) need to be integrated into a geomodel and then into a numerical model domain that is consistent with available information to generate predictions of plume and pressure front movement.

The CTV injection wells will inject into the Monterey Formation's A1-A2 Sands in the Elk Hills Oil Field (EHOF) within the San Joaquin Valley of California. The injection zone is within the Northwest Stevens Anticline, a northwest-southeast trending anticlinal structure located in the EHOF. The injection zone consists of stacked turbidite sands within the Monterey Formation and is interbedded with siliceous shales and clays. The Monterey Formation A1-A2 Sands pinch out towards the southeast, while the lowermost sands are present across the entire structure (as seen in Figure 1 of the AoR CA). The confining unit above the Monterey Formation is the Reef Ridge Shale, which is a regionally extensive deep marine, clay-rich interval with an average gross thickness of about 1,000 ft and a low matrix permeability. It has acted as the primary sealing unit for all Monterey Formation accumulations in the EHOF based on historical production well performance.

CTV used geologic and hydrologic data derived from multiple sources for their geomodel and numerical modeling approach. These sources include well data, open-hole well logs and core (Figure 2 in AoR CA), and reservoir performance information (including production and injection rates and volumes, reservoir, and wellbore pressures). The representation of site geologic features, including lithologic properties, geomechanical behavior, and fault presence, appears to be appropriate and is reflected in the applicant's static geomodel and computational model. However, some information was omitted, including the injection zone fracture pressure derivation and stratigraphic discretization.

Questions/Requests for the applicant:

- *Please show the location of CTV's proposed Class VI injection wells in Figure 2 of the AoR CA. Additionally, provide a legend defining the various well icons in the figure.*

Representation of Hydrogeologic Properties and Lithology

Porosity, permeability, and rock types

Figure 3 of the AoR CA shows well penetrations that have data from open hole triple-combo logs (resistivity, neutron porosity, bulk density) and core data. Model parameters including porosity, facies, and clay volume were derived from the open hole logs and upscaled into the geological model using Gaussian random function simulation (kriging). Mercury injection capillary pressure (MICP) permeability data from core analysis was used to constrain the porosity-permeability function seen in Figure 5 of the AoR CA. Permeability is a function of porosity and clay volume. Figure 7 shows that the highest porosity and permeability values exist near the crest of the anticline, with decreased values on the limbs of the anticline. Additional discussion of porosity and permeability is included in pgs. 17-20 of the permit application narrative.

Questions/Requests for the Applicant:

- *The correlation coefficient in Figure 5 is illegible. Additionally, it is unclear what value (porosity or clay volume) is represented on the X-axis. Please render the correlation coefficient so that it is legible and clarify what value is used on the X-axis.*
- *The axes in Figure 6 are illegible. Please edit this figure so the X and Y axes are legible.*

Geomechanical properties

The geomechanical properties of the Monterey Formation A1-A2 reservoir and Reef Ridge Shale confining zone were derived from compressional sonic data and MICP measurements in 18 wells. Borehole breakout data from the EHOF and literature reviews also aided in characterizing fracture behavior. A corresponding geomechanical model was generated to assess the failure pressures for the reservoir and confining zone. CTV included relevant discussion concerning geomechanical modeling and properties in the permit application narrative; please also see the geologic site characterization report for discussion.

A summary of fracture pressure data for the Monterey Formation A1-A2 reservoir is provided in Table 6 of the AoR CA, which is replicated below. The applicant states that injection pressure will be below 90% of the Monterey Formation A1-A2 fracture gradient at the shallowest point of the Reef Ridge Shale base in the AoR (8,403 ft as seen in Table 7 of the AoR CA, replicated below). The planned maximum subsurface wellbore injection pressure for the project is 4,500 PSI.

Table 6: Summary of the fracture pressure data for the Monterey Formation A1-A2 reservoir.

Interval	Fracture Gradient PSI/foot	Fracture Pressure (PSI) at base of Reef Ridge Shale (8,403 feet)
Monterey Formation A1-A2	0.97	8,150

Table 7. Injection pressure details.

Injection Pressure Details	Injection Well 1 357-7R	Injection Well 2 355-7R
Fracture gradient (psi/ft)	0.97	0.97
Maximum injection pressure (90% of fracture pressure) (psi)	7,335	7,335
Elevation corresponding to maximum injection pressure (ft MSL)	8,403	8,403
Elevation at the top of the perforated interval (ft MSL)	8,485	8,462
Calculated maximum injection pressure at the top of the perforated interval (psi)	7,407	7,387
Planned maximum injection pressure / gradient (top of perforations)	4,500 / 0.53	4,500 / 0.53

Questions/Requests for the Applicant:

- *What data from which tests were used to establish the fracture pressure listed in Table 6 of the AoR CA? Additionally, please discuss how testing during the pre-operational phase will further establish the fracture pressure of the injection zone. If Step Rate Testing (SRT) will be used to determine fracture pressure, please describe the testing procedure, including the fluid to be used and how it is representative of the CO_2 injectate.*
- *The elevations at the top of the perforated intervals (ft MSL) for Injection Wells 357-7R and 355-7R in Table 7 of the AoR CA do not correspond with the perforated interval depths for these Injection Wells in Table 5 of the AoR CA. Please revise this discrepancy and edit Table 5 and/or Table 7 accordingly.*
- *The planned injection pressure / gradient for Injection Wells 357-7R and 355-7R is listed as 4,500 psi / 0.53 psi/ft in the last row of Table 7 of the AoR CA. Please clarify if these values are indeed a maximum, or if they are a planned injection pressure/gradient. If they are not a maximum, please edit Table 7 to exclude the word "Maximum" in "Planned maximum injection pressure / gradient (top of perforations)."*

Objectives for Pre-Operational Testing:

- *Confirm the fracture pressure of the injection and confining zones, i.e., by performing an SRT in each zone.*

Geomodel – 3D model grid resolution and discretization

The Petrel static geomodel was used as the framework for the GEM numerical model. The geo-cellular grid is uniformly spaced throughout a 6.4 square mile area with a cell size of 150 ft x 150 ft. The model grid is oriented at 55 degrees, which corresponds to both the structural trend of the anticline and the depositional environment. The model boundaries were selected based on plume extent and the peripheral area of elevated pressure.

The reservoir was separated into two zones, corresponding to the A1 and A2 sands, each with 8 and 13 layers respectively and an average grid cell height of 11.5 ft (Figure 4 in AoR CA). Grid resolution was idealized based on simulation run-time and retaining reservoir heterogeneity. Note that the grid files were not submitted to the GSDT because, as CTV noted, the file is too large. However, the grid files are not needed at this time to support the evaluation.

Questions/Requests for the Applicant:

- *Please discuss how the lateral dimensions and vertical thickness of the Petrel static geomodel were chosen, and the significance of such values (i.e., 10 miles x 10 miles laterally, 3,000 ft thick).*
- *Please discuss how the total grid dimensions laterally and vertically (i.e., 200 x 200 cells laterally, 50 layers vertically) were chosen.*
- *Please discuss the vertical layers (stratigraphy) that were included in the model and why cell size height may vary between vertical layers.*
- *Please discuss why the Monterey Formation A1-A2 Sands were modeled as two separate zones, when according to the geologic narrative, they comprise a single hydraulically connected injection zone.*
- *Please show the extent of the AoR and the location of CTV's proposed Class VI injection wells in Figure 3 of the AoR CA.*
- *Please label the vertical layers shown in Figure 4 of the AoR CA, especially the injection and confining layers. Additionally, please show the location of CTV's proposed Class VI injection wells on the inset base map and cross-sectional views.*

Fault stability

Faults were not incorporated into the geomodel due to the lack of evidence of faults that transect the Monterey or Reef Ridge Shale Formations in the AoR. CTV included relevant discussion concerning fault stability in the permit application narrative; please also see the geologic site characterization report for discussion.

Evaluation of the Computational Model Design

The applicant's discussion of computational model design includes but is not limited to subsurface phase properties and behavior, CO_2 plume size and extent, boundary and initial conditions, timeframe and time steps, operational information, model calibration and sensitivity analysis, and injection zone storage capacity. EPA considers the applicant's evaluation of the computational model design and associated components to be appropriate and relatively complete, however there are several outstanding questions that need to be addressed in order to consider the material in this section sufficient. These questions are included under "Questions/Requests for the Applicant" in each of the following sub-headings, below.

Routines for Relevant Subsurface Processes

The applicant used Computer Modeling Group's (CMG) Equation of State Compositional Simulator (GEM) to perform the AoR delineation. GEM is capable of modeling three components (gas, oil and aqueous), multi-phase fluids, predict phase equilibrium compositions, densities, and viscosities of each phase. The applicant states that CMG incorporates all relevant physics-based approaches to relate relative permeability to interfacial tension (IFT), velocity, composition, and hysteresis. CTV also referenced multiple CO_2 sequestration peer reviewed papers in which CMG's GEM software has been used. The Peng-Robinson Equation of State is used for the computational modeling of the CO_2 plume, and establishes the interaction or solubility of CO_2 and residual oil in the reservoir. The solubility of CO_2 in water is modeled by Henry's Law as a function of pressure, temperature, and salinity.

The permit application states that the evolution of the CO_2 plume involved: integrating reservoir characteristics and wells found in the static Petrel 3D geomodel; inputting injection pressure and rates in the GEM computational modeler; and assessing CO_2 plume movement throughout the injection and post-injection intervals until the plume reached pressure and compositional equilibrium.

Spatial extent

The AoR was determined by the largest extent of the CO_2 plume from computational modeling results. In the AoR scenario, CO_2 was injected into the reservoir until the reservoir reached the initial discovery pressure of 4,000 psi. This process ensures that there is no increased pressure front beyond the original reservoir limits.

Questions/Requests for the Applicant:

- *Please explain the specific method used to define the AoR boundaries (i.e., percent CO_2 saturation cutoff or a qualitative method).*

Boundary conditions

No-flow boundary conditions were established for the Monterey Formation A1-A2 reservoir in the computational modeling. The overlying confining unit, the Reef Ridge Shale, is continuous through the area, has a low permeability (less than 0.01 mD), and has confined oil and gas operations (that include injection) since discovery of the field. Well performance data from the Monterey Formation A1-A2 oil and gas reservoir, shown in Figure 9 of AoR CA, indicates no connection to an aquifer. Historical production shows minimal water production, supporting the lack of aquifer connectivity. Gas injection and subsequent gas blow-down supports lateral and vertical confinement by demonstrating that gas did not migrate out of the reservoir. Finally, reservoir pressure is approximately 230 psi and has not shown an increase due to aquifer influx.

Questions/Requests for the Applicant:

- *Please provide historical pressure data for the Monterey Formation A1-A2 reservoir demonstrating pressure isolation.*

Time Steps and Model Timeframe

The computational modeling results for CO_2 plume development at 4 different time-steps are shown in plan view (Figure 10) and cross-sectional view (Figure 11). The time-steps are Year 2 injection, Year 4 injection, Year 50 post injection, and year 100 post injection. The model simulation appears to have occurred over a 115-year timeframe (i.e., the 15-year injection phase plus 100 years post-injection), but this is not clear. For all layers within the model and at all time-steps, the CO_2 plume remains within the 2.1 square mile AoR. Within the first 2 years of injection, the CO_2 plume is largely defined. After 2 years, the CO_2 concentration within the plume increases until the 50 years post injection time-step. The CO_2 concentration is largely unchanged between the 50-year and 100-year post injection time-steps.

CO_2 injected into the Monterey Formation A1-A2 reservoir will be soluble in both water and oil. Due to the low remaining oil and water saturations in the reservoir, the injected CO_2 that will be dissolved in oil and water is predicted to be 0.5% and 1.3%, respectively. The remaining 98% of the injectate will be stored in the reservoir as supercritical CO_2. Figure 12 of the AoR CA demonstrates the cumulative storage for each of these mechanisms (oil, water, supercritical CO_2).

Questions/Requests for the Applicant:

- *Please add the injection wells to Figures 10 and 11.*
- *Please label the vertical layers on Figure 11.*
- *Please provide additional time steps in Figures 10 and 11, in particular, to represent the full extent of the injection phase (i.e., to the end of the injection phase) and the early post-injection phase (e.g., at 1, 3, 5, and 10 years after cessation of injection).*
- *Please add a discussion regarding the time at which the CO_2 plume is expected to reach its maximum vertical and lateral extent. Additionally, please discuss the boundaries at which this extent is defined.*
- *Please clarify the total simulation period (i.e., whether it is 100 years total or the injection period plus 100 years).*
- *Based on Figure 12, there is no additional CO_2 to be stored after year 5 of injection; however, the permit application narrative indicates injection will occur for 15 years. Please clarify this difference.*

Initial Conditions and Operational Information

Initial model conditions at the beginning of CO_2 injection have been established and verified over time during oil and gas production from the Monterey Formation A1-A2 reservoir. Initial conditions for the model are given in Table 4, which is replicated below. Operational information is presented in Table 5.

Table 4. Initial conditions.

Parameter	Value or Range	Units	Corresponding Elevation (ft MSL)	Data Source
Temperature	240	Fahrenheit	8,300	Fluid Analysis
Formation pressure	200-300	Pounds per square inch	8,300	Pressure Test
Fluid density	61	Pounds per cubic foot	8,300	Water analysis
Salinity	25,000	Parts per million	8,300	Water analysis

Table 5. Operating details.

Operating Information	Injection Well 1 357-7R	Injection Well 2 355-7R
Location (global coordinates) X Y	 35.32802963 -119.5449982	 35.33139038 -119.5441437
Model coordinates (ft) X Y	 6,100,956.63 2,308,944.30	 6,101,103 2,310,474
No. of perforated intervals	7	4
Perforated interval (ft MSL) Z top Z bottom	 7,728 8,010	 7,774 7,949
Wellbore diameter (in.)	7	7
Planned injection period Start End	 02/01/2024 04/01/2039	 02/01/2024 04/01/2039
Injection duration (years)	15	15
Injection rate (t/day)*	648 – 1,917	648 – 1,917

Questions/Requests for the Applicant:

- *The initial conditions in Table 4 were established at a depth of 8,300 ft MSL. The perforation intervals for Injection Wells 357-7R and 355-7R specified in Table 5 are above 8,300 ft MSL. Please explain how the initial conditions at a depth of 8,300 ft MSL would be representative of the perforation intervals in Injection Wells 357-7R and 355-7R.*
- *Please add the reference elevation to Table 4.*

Relative permeability and capillary pressure curves

Gas, oil, and water are all present in the Monterey Formation A1-A2 reservoir. Contact depths have been derived from open-hole logs, production analysis, and history matching, and saturations have been assumed; however, the plan does not provide the basis for the assumptions. With all three phases present in the reservoir, three-phase relative permeability relationships were used in the computational model to characterize the flow of each phase. To determine three-phase relative permeability, two sets of two-phase relative permeability data are needed: water-oil and gas-oil relative permeability. The two-phase relative permeability relationships allow the determination of Krw, Krow, Krg, and Krog as a function of water or liquid saturation. Core flood and MICP data were used to determine the two-phase relative permeability relationships. Figure 8 of the AoR CA presents the relative permeability curves used in the computational modeling.

Questions/Requests for the Applicant:

- *Please explain the method used for determining the saturation values for gas, oil, and water.*
- *Please include definitions for Krw, Krow, Krg, and Krog.*

- *Please explain how the relative permeability relationships vary with rock type, and how these permeability relationships were derived.*

Potential Pathways for Fluid Movement

Faults

CTV included relevant discussion concerning fault stability in the permit application narrative; please also see the geologic site characterization report for discussion.

Wells in the AoR

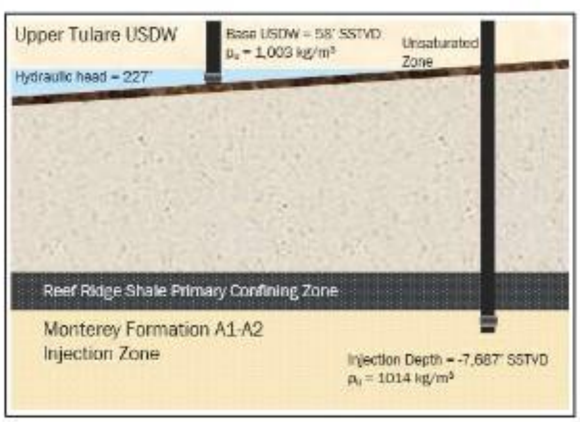
The AoR CA says that complete documentation of the 152 wells in the AoR (tabulated in Table 8 of the AoR CA) that penetrate the Reef Ridge Shale confining zone is given in Appendix 1, and Figure 15 of the AoR CA shows a map view of the 152 wells that penetrate the Reef Ridge Shale confining layer and Monterey Formation A1-A2 reservoir. However, it is unclear how many of the 152 wells penetrate the entire Reef Ridge Shale or are completed in the Reef Ridge Shale, and if they are accounted for in the computational model. Additional discussion regarding wells in the AoR is presented under “Corrective Action on Wells in the AoR,” below.

Calculation of critical pressure

CTV submitted their critical pressure calculation to the GSDT in a file titled “Critical—Pressure—Calculation.PDF.” Using the inputs from Figure 4 and equation listed on pg. 3 of the Critical—Pressure—Calculation PDF, the critical pressure was calculated to be 3,400 psi. The final pressure of the Monterey Formation A1-A2 reservoir will be at or below the initial reservoir pressure of 4,000 psi, ensuring that post-injection conditions replicate those of initial conditions to the extent possible. Therefore, the AoR is based on the extent of the modeled CO_2 plume.

$$\frac{P_{i,f}}{\rho_i g} + z_i = \frac{P_u}{\rho_u g} + z_u$$

Figure 4: Schematic section of the storage site with inputs to critical pressure calculation. Values for the USDW are based on the 326-7R well. The injection depth is based on the 357-7R injector. Using data from wells 357-7R injector and 326-7R the critical pressure is 3,400 PSI.



Questions/Requests for the Applicant:

- *Please define the variables shown in the critical pressure calculation and their corresponding values shown in Figure 4 of the Critical—Pressure—Calculation PDF.*
- *The injection depth shown in Figure 4 of the Critical—Pressure—Calculation PDF (7,687 ft SSTVD) is different than the perforated depths shown in Table 5 of the AoR CA (7,728 ft MSL). Please confirm that this difference is due to ground level reference elevation. If not, please change the depth in Figure 4 and/or Table 5 to reflect the correct injection depth.*
- *If any of the 152 wells in the AoR penetrate the entire Reef Ridge Shale, please explain how they are accounted for in the geomodel.*

Representation of Fluid Properties

Because a baseline injectate analysis has not yet been performed, limited information about the CO_2 stream is available and relevant CO_2 injectate fluid properties for the numerical modeling are not included in the AoR CA. The applicant did not submit an operating plan for the proposed wells with this information. Additionally, the applicant did not include reactive transport modeling as part of the overall modeling effort. It appears this might be due to the low water saturation (~15%) and dominant quartz/feldspar mineralogic framework of the reservoir, as noted in the permit application narrative. However, an explanation regarding the lack of reactive transport modeling is needed.

Questions/Requests for the Applicant:

- *Please update the AoR CA to include fluid properties for the CO_2 injectate used in the computational modeling, including but not limited to viscosity, density, salinity, and fluid compressibility.*
- *Please explain why reactive transport modeling was not performed or included in the computational model.*

Objectives for Pre-Operational Testing:

- *Confirm that the properties of the CO_2 stream based on pre-operational injectate sampling are consistent with the model inputs.*

Model Calibration and Sensitivity Analyses

CTV used information derived from extensive past injection operations to inform a sensitivity analysis. The CO_2 plume model results were compared with the area of the reservoir that has been depleted by oil and gas operations.

As a computational model sensitivity, CTV maintained the injection rate for 9 years, with an increase in the final post-injection pressure and total CO_2 injected. The left panel in Figure 13 of the AoR CA represents this scenario, and the panel on the right demonstrates CO_2 plume development at a post injection reservoir pressure equivalent to the initial reservoir pressure. At a final reservoir pressure of 5,750 psi, which is greater than the initial reservoir pressure of 4,000 psi, the reservoir can store 193 BCF of CO_2, which is an increase of 61 BCF relative to initial reservoir pressure storage capacity. Both scenarios demonstrating the difference in CO_2 plume development are depicted in Figure 13 at 100 years post injection. The CO_2 plume remains within the AoR in both scenarios, with CO_2 concentrations increasing in the northwestern portion of the AoR. The applicant concludes that this scenario demonstrates that the AoR is consistent with a larger volume of injected CO_2 and the potential impact to the Upper Tulare USDW is conservative. Monitoring wells will be used for CO_2 plume and pressure front tracking, via fluid sampling and pressure and temperature monitoring. Reservoir pressures based on monitoring data and injection volumes will be integrated in order to complete material balance equations to verify pore volumes and AoR edges. Additionally, the CO_2 plume and water contact will be calculated from the monitoring well pressure, CO_2 saturation, and column height. If the reservoir pressure associated with injected volumes does not follow the anticipated trend from computational modeling, CTV will reevaluate the AoR. (Additional evaluation of the proposed plume and pressure front tracking will be presented in the Testing and Monitoring report.)

Questions/Requests for the Applicant:

- *Please discuss the genesis and evolution of minor CO_2 concentrations pictured in Figure 13 in the central to eastern portions of the AoR.*
- *Please provide a version of Figure 13 corresponding to the end of the injection period and/or the time at which the plume and pressure front are expected to be at their maximum extent.*
- *Was a sensitivity analysis conducted on grid geometry and petrophysical properties?*
    - *If so, please discuss the sensitivity analysis and its results.*
    - *If not, please perform a sensitivity analysis*

Injection Zone Storage Capacity

As stated in the "Model Calibration and Sensitivity Analyses" section above, the storage capacity of the injection zone appears to be 132 BCF of CO_2 at initial reservoir pressure conditions of 4,000 psi (193 BCF minus 61 BCF as mentioned in the discussion of Model Calibration and Validation of the AoR CA, pg.15). The injection zone does have the potential to store an increased volume of CO_2 at higher pressures while the CO_2 remains within the defined AoR.

Questions/Requests for the Applicant:

- *The modeled injection zone storage capacity is not explicitly stated in the AoR CA. Please confirm if the volume of 132 BCF is correct. If it is not correct, please provide the correct volume.*

Presentation of Model Results

Map and cross-sectional views of the simulated plume and pressure front were provided in the AoR CA. The maps show the position of the plume and pressure front after 2 years and 4 years of injection, and 50 years and 100 years post-injection. Figures 10 and 11 show the applicant's proposed AoR as delineated by the simulated CO_2 plume.

The differences in the predicted position of the plume and pressure front between the injection and post-injection time-steps were minor, suggesting that the plume movement may remain stable after injection ceases. Updated modeling will be necessary when pre-operational site data becomes available.

Corrective Action on Wells in the AoR

The AoR CA says that documentation of the 152 wells in the AoR that penetrate the Reef Ridge Shale confining zone is provided in Appendix 1. However, no tabulation of these wells is provided. There is an

Excel file (AoR—Well--List) containing the name, surface location, and status of 152 wells, but it does not contain information on drill date, type, and depth to Reef Ridge Shale confining zone that is required at 40 CFR 146.84 (c)(2). Table 8 of the AoR CA indicates that 40 of the 152 wells are plugged (which corresponds to information in the Excel file). Figure 15 of the AoR CA shows a map view of the 152 wells that penetrate the Reef Ridge Shale confining layer and Monterey Formation A1-A2 Sands. These wells were reviewed for corrective action.

All 152 wells in the AoR penetrate the confining zone. This determination was made by reviewing open hole logs and deviation surveys of each well. The AoR CA plan says that well condition, mechanical integrity and data completeness is routinely reviewed with CalGEM. The wells located within the AoR were last reviewed in Q1 of 2021.

The AoR CA also states (pg. 18) that 14 wells (shown in Table 9) will be plugged before commencement of CO_2 injection. These are abandoned wells that penetrate and are currently perforated in the Monterey Formation A1-A2 Sands or the Etchegoin Formation. It is unclear based on the text if these are the only wells that penetrate entirely through the Reef Ridge Shale, however.

The AoR CA plan says that the corrective action assessment for each well in Appendix 1 included the generation of wellbore/casing diagrams, determination of cement tops for each casing string, review of open perforations and cement plug depths. However, Appendix 1 has not been provided.

Protection of the USDW was determined by assessing all wells within the AoR that penetrate the Reef Ridge Shale. Wells were determined to not need corrective action if they had: surface or intermediate casing over the USDW; were cemented over the USDW; had cement in the intermediate casing-surface casing annulus, above the surface casing shoe; and there was cement in the production casing annulus, above the Reef Ridge Shale. The application states that all wells within the AoR meet these criteria.

Questions/Requests for the Applicant:

- *Please provide additional documentation to support the statement that all the wells meet the corrective action evaluation criteria for protection of the USDW, as described on pg. 18. For example, are the wells that penetrate the Reef Ridge Shale confining zone and Monterey Formation A1-A2 Sands cemented over these zones? If cement coverage is absent for these wells over the Reef Ridge Shale confining zone and Monterey Formation A1-A2 Sands injection reservoir, it may be necessary to address corrective action of these wells in the AoR CA Plan.*
- *Please provide Appendix 1. The table should include a description of each well's type, construction, date drilled, location, depth, and record of plugging and/or completion, as required at 40 CFR 146.84 (c)(2).*
- *Please provide the plugging and abandonment (P&A) procedure for the 14 wells identified in Table 9 of the AoR CA to demonstrate that plugging will ensure isolation of the Monterey Formation A1-A2 Sands.*
- *Please clarify the distinction of the 14 wells on Table 9 to be plugged. Specifically, are these wells deficient in any manner; are they the only wells that penetrate the entire thickness of the Reef Ridge Shale; or, are they just slated to be plugged as part of field operations?*
- *Please denote Injection Wells 357-7R and 355-7R, the monitoring wells, and the 14 wells to be plugged on Figure 15 of the AoR CA.*

AoR Reevaluation Schedule

CTV described the procedures and timing for AoR reevaluations to be performed during the injection and post-injection phases, and the information that will be considered in the reevaluations. At this point in the permit application review, the five-year default reevaluation schedule in the Class VI Rule appears to be appropriate.

Questions/Requests for the Applicant:

- *EPA requests the following revisions to the AoR reevaluation procedures to provide a more robust analysis:*
    - *Include a review of the full suite of water quality data collected from monitoring wells in addition to CO_2 content/saturation (to evaluate the potential for unanticipated reactions between the injected fluid and the rock formation). Also, review and provide any geologic data acquired since the last modeling effort, including any additional site characterization performed for future injection wells.*
    - *Clarify that the reevaluation modeling results will be compared with the most recent modeling (i.e., from the most recent AoR reevaluation).*
    - *Specify that, if the results of the modeling comparison are consistent, a report describing this determination will be provided.*
    - *Describe the specific actions that will be taken if there are discrepancies between monitoring data and prior modeling results (e.g., remodel the AoR, update all project plans, perform additional corrective action if needed, and submit the results to EPA).*

Triggers for AoR Reevaluations Prior to the Next Scheduled Reevaluation

An unscheduled reevaluation of the AoR will take place if any of the following scenarios occur:

1) Change in operations such as an increase in injection rates, or injection pressure.

2) Differences between the computational model for CO_2 plume development and observed CO_2 plume development, including unexpected changes in fluid content or pressure outside of the Monterey Formation A1-A2 reservoir that are not related to well integrity, or reservoir pressure that does not behave as predicted with increased injection volumes.

3) Seismic events occur that indicate the presence of faults near/intersecting the confining zone; events that are larger than a 3.5 magnitude and that could be associated with CO_2 injection.

CTV will discuss any such event with the UIC Program Director to determine if an AoR reevaluation is necessary. If an unscheduled reevaluation is triggered, the AoR reevaluation procedures described in the AoR CA plan will be initiated.

Questions/Requests for the Applicant:

- *Please describe the specific injection rate and injection pressure increase CTV referenced that would necessitate an AoR reevaluation, and how such an increase would not involve an exceedance of permit limits.*
- *Please clarify the degree of change in reservoir pressure (e.g., outside three standard deviations from the average) that would be needed to necessitate an AoR reevaluation.*

- *Please clarify the timing for conducting an AoR reevaluation (i.e., within 6 months) if any of the triggering events occur.*
- *Please clarify the area over which seismic events greater than M3.5 (e.g., consistent with the Emergency and Remedial Response Plan) would trigger an AoR reevaluation.*
- *EPA recommends that the following events be added to the triggers for an AoR reevaluation:*
    - *Exceeding 90% of the geologic formation fracture pressure in any injection or monitoring wells.*
    - *Detection of changes in shallow groundwater chemistry (e.g., a significant increase in the concentration of any analytical parameter that was not anticipated by the AoR delineation modeling).*
    - *Initiation of competing injection projects within the same injection formation within a 1-mile radius of the injection well (including when additional CTV injection wells come online);*
    - *A significant change in injection operations, as measured by wellhead monitoring;*
    - *Significant land-use changes that would impact site access; and*
    - *Any other activity prompting a model recalibration.*

Post-Injection Site Care Plan

Certain elements of the applicant's Post-Injection Site Care (PISC) and Site Closure Plan (Attachment E) are based on the modeling effort and the results and are evaluated below. See also the Testing and Monitoring report (for an evaluation of CTV's post-injection monitoring plan).

As required in 40 CFR 146.93(a)(2)(i) and (ii), the applicant presented the pre- and post-injection pressure differentials and associated maps in the AoR CA. Figure 3 of Attachment E shows the predicted maximum extent of the CO_2 plume and pressure front at site closure.

Figures 4 and 5 of Attachment E show the injection and monitoring wells, and the predicted extent of the CO_2 plume in plan view and cross-sectional view, respectively.

Questions/Requests for the Applicant:

- *Figure 1 in Attachment E shows the reservoir pressure stabilizing at the same time as injection cessation. Please clarify if reservoir pressure will stabilize at this point, or if pressure will stabilize a year after injection cessation as noted in Attachment E, "Pre- and Post-Injection Pressure Differential [40 CFR 146.93(a)(2)(i)]."*
- *Please update Figure 1 to reflect the planned 15-year injection period.*
- *CTV submitted an updated version of Attachment E in December 2021; however, this document appears to be identical to the initial plan submitted in August 2021. Please clarify what information was updated in the December 2021 version.*

Post-Injection Site Care Time Frame

The applicant proposed a 50-year post injection site care time frame and will not cease post-injection monitoring until a demonstration of non-endangerment of USDWs has been approved by the UIC Program Director pursuant to 40 CFR 146.93(b)(3). The applicant is not proposing an alternative post-injection site care timeframe, so no evaluation relative to the criteria at 40 CFR 146.93(c) is needed.

Non-Endangerment Demonstration Criteria

CTV did not identify the contents of or criteria by which it would support a non-endangerment demonstration at the end of the post-injection site care phase. EPA recommends that CTV propose and include in the PISC and Site Closure Plan a set of criteria that are as specific as possible and can be supported by the data CTV will collect during injection and post-injection testing and monitoring. Incorporating this into the PISC and Site Closure Plan will help reduce future uncertainty and help ensure that CTV will collect the types and amounts of data that are needed to inform a demonstration that site closure is appropriate. EPA recommends that the non-endangerment demonstration criteria address the evaluation of available groundwater and plume monitoring data; comparison of monitoring data to model predictions; evaluation of the CO_2 plume and reservoir pressure; and an evaluation of any unanticipated events that occurred during the project. See, e.g., Section 3.4 of EPA's "UIC Program Class VI Well Plugging, Post-Injection Site Care, and Site Closure Guidance."

Some specific recommendations to support the preparation of a section of the PISC and Site Closure Plan related to non-endangerment demonstration criteria are provided below:

- *The criteria should specify that the same delineation model that supported the initial AoR delineation will be used in AoR reevaluations and to make the non-endangerment demonstration. This will facilitate verification and/or model calibration using actual monitoring and operational data.*
- *The criteria should discuss the predicted behavior of the CO_2 plume and pressure front, supported by maps and graphs (e.g., of pressure profiles or extent of the plume and pressure front) in the context of the data that will be collected to demonstrate that the plume and pressure front are behaving as predicted at various points in time.*
- *The data that will support the non-endangerment demonstration should be consistent with the final injection and post-injection phase testing and monitoring strategies in Attachments C and E. They should also be specific as to the types/locations of data that will be gathered and compared against the model prediction to facilitate model validation (e.g., the formations for which groundwater quality data will be collected and pressure monitoring locations).*
- *The criteria should include an evaluation of natural and artificial potential conduits for fluid movement.*
- *The non-endangerment criteria should include evaluations of mobilized fluids and passive seismic data.*
- *The non-endangerment criteria should include a summary of any emergencies or other unanticipated events that may occur during the injection and post-injection phases. This may be presented in a table that shows (1) examples of unanticipated events that might occur, and (2) the types of data that might be used to demonstrate that any associated issues have been resolved such that they will no longer endanger USDWs.*